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ANALYSIS OF AIRBORNE FINES IN CYLINDRICAL BIOMASS STORAGE SILOS

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Abstract. Biomass handling industries are transporting and storing huge quantities of biomass materials. During transportation, wood pellets can be subject to attrition (a process that generates additional fines and dust). When filling large volume storage silos the fines tend to concentrate in certain areas within the silo, depending upon the size of the particles and their sensitivity to the method of filling (Zigan et al. 2008). These particles are easily made airborne when discharged from the storage and can represent an increased health related hazard as well as dust explosion hazards. The risk of dust explosions increases with the size of storage. Previous researchers have developed dust explosion models in order to assist practitioners from industry to minimise the health and safety risks for their plants[1].

This research studies the significance of airborne fines concentration in different silo locations. The fines concentrations will be evaluated according to analysis approach described first in Zigan et al. 2008. The experimental silo is cylindrical and a mixture fines and coarse particles will be fed by gravity centrally into the silo.

It was found that fines tended to accumulate near the silo wall. This can partly be explained by a segregation phenomenon called air current segregation (ACS). ACS is present in the silo as an effect of both circulating air currents generated by the falling particle jet. The fines reach the terminal velocity before the coarse particles then the fines follow the dominant air flow direction.

This research shows the importance of including a consideration of the fines concentration in any modelling approach developed to indicate the propagation and mobilisation of fugitive particulate material during filling operations.

1 INTRODUCTION

Transporting and storing large quantities of bulk materials is common to most of the industries related to bulk-solids handling. (i.e. Drax Power Station which produces 7% of the UK electricity and burns ~12m tonnes of wood pellets annually). Among them, the biomass handling industries are very common. One of the most hazardous incidents which occurs in biomass industry are dust explosions.

Fines are generated due to breakage of wood pellets during transportation and filling processes. During handling dust gets airborne and creates a dust cloud in silos and other enclosed vessels. The creation of the dust is very hazardous in many aspects. One of the main hazards is the health issues the operators can face as a cause of inhaling the dusty air[2]. And the other issue is that concentrated dust can create dust explosions at certain levels of dust concentration.
Although some protection and safety overalls can be worn in order to avoid the health hazard, the risk of dust explosions remains the same. critical levels of dust concentrations have been found through a number of experiments and software calculations[3]. Thus the remaining necessity is to predict the concentrations of dust at different locations in silos and the other filling vessels.
Therefore this paper introduces an experiment of locating the airborne dust/fines concentrations through investigating the dust settlement at the bottom of silo. In addition to that there are findings relating to the behaviour of air-currents in the vessel during the filling process.
The main focus of this paper is on the amount of dust generated due to the air current segregation during the filling process of biomass storage silos.
There are a number of researches [1] which have focused on investigating the segregation of fine particles along with the air-currents in silos during the filling procedure which can be referred to as air current segregation. But most of the researches focused on materials which have less diversity in terms of particle size.
According to Zigan et al. alumina powder segregates at higher filling rates [1]. Alumina powder requires a higher filling rates as alumina powder has the characteristics which shows less separation of fines from the main particle jet during the filling. That experiment shows it is required to use a mixture of materials with a good diversity of particle sizes.
Therefore this paper is particularly focused on using a mixture of saw dust and wood pallets consisting of two known particle sizes which have a good diversity of particle sizes.

1.1 Concepts

This experiment is designed on two arguments.

- Concentration of the fines in the collectors at the edge depends on the air flow patterns created by the falling particle jet.
- As this mixture is consists of particles with two different sizes, a constant flow of the falling particle jet cannot be expected. Instead a particle jet with a spiral shape can be expected. This is due to the separation of the fine particles form the coarse particles.
- This effect might depend on size of the opening. Which is not focused in this paper.

Furthermore, the expected settlement of dust at the end of experiment should be a vertical fall under the terminal velocity. The reason is there should be no interactions or trajectories between particles.

2 METHODOLOGY

2.1 The rig

A rig has been built previously for the purpose of investigating the scaling rule of air-current segregation of alumina powder [1]. I has been preliminary identified that the rig is ideal for the current experiment after some minor modifications. The modifications that have been added are:

- Modified feeding mechanism: The current feeder has been designed for use with alumina powder. But as the mixture of saw dust with wood pallets (broken) that has been used in this experiment has the characteristics of a mass flow. Therefore the feeding mechanism has been rebuilt with a gravity feeder designed for a mass flow[4].
- Air extractors: The rig has been originally built with four air extractors and flow meters attached. In this particular experiment the air extraction has been adjusted to extract 10.575 Litres per minute, which is equal to the volumetric feeding rate of the material.

  Material collectors (sample pouches) at the bottom of the rig: As the original design of the rig was for alumina power, which had the flowability of a core flow could easily flow through the bottom orifice of collectors. Because the new material a mass flow like behaviour a set of bags has been used instead of the orifices at the bottom.

Figure 1 : Bottom
(collectors) of the rig

2.2 Sample Preparation

The aim of the experiment was to investigate the effect of the dust generation due to air-current segregation when using materials which have different sized particles to fill a silo. Therefore this experiment has been conducted with a material consisting of two different sized particles of the same material. Broken wood pellets which have a size range between 3.15 mm to 4.75 mm have been used as the coarse particles of the mixture. These coarse particles were mixed with the fines of the same material with a size range of 0.1 µm to 500 µm. The mixture consists the ratio (weight) of 1: 10 between the fines and the coarse material.

Coarse material
(Size: between 3.15 mm to 4.75 mm)

Fines
(Size: < 500 µm)

Mass Ratio → 10 : 1

Figure 2 : Materials combination

The final mixture which has been used for the experiments had a weight of 1100 grams with 100 grams of fines and 1000 grams of coarse materials.

2.3 Experimental

The mixture has been fed into the rig from the top opening with the aid of a gravity feeder. Then the air extractors were activated while the filling process to extract the air inside the rig. The extractors were calibrated to extract air in the same feeding (volumetric) flow-rate as the biomass mixture. Simultaneously a high-speed video with 224 fps and a resolution of 224x160 of the flow has been captured. The experiment was stopped after feeding 1100 grams of materials. Then the settled dust at the bottom of the silo has been analysed.

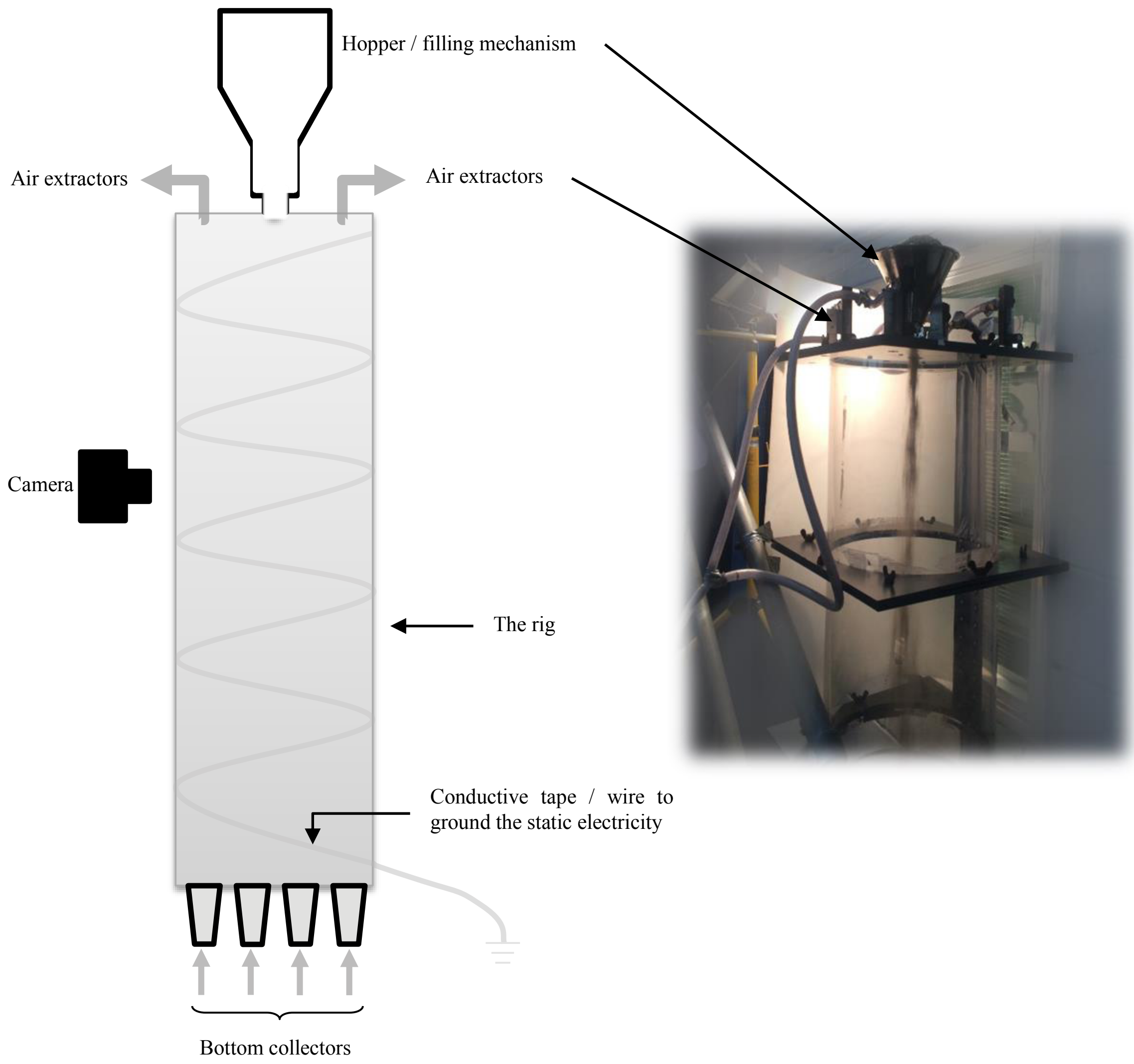


Figure 3 : Schematic overview of the rig and the actual rig

3 RESULTS AND DISCUSSION

3.1 Mass distribution

The total mass distributions are presented in Figure 4 and 5. The weight distribution of the settled dust was centred in to the middle of the collectors.

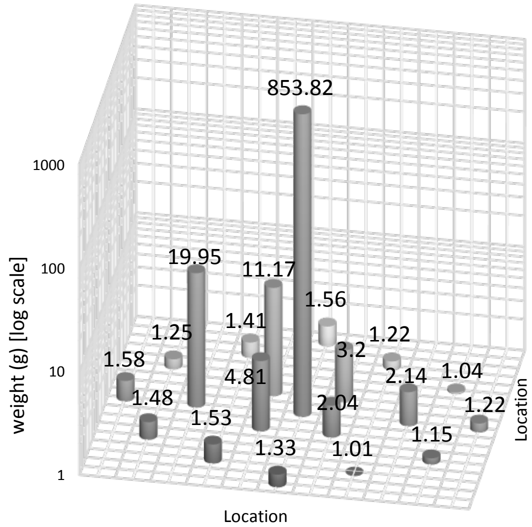


Figure 5 : mass distribution of Test 1

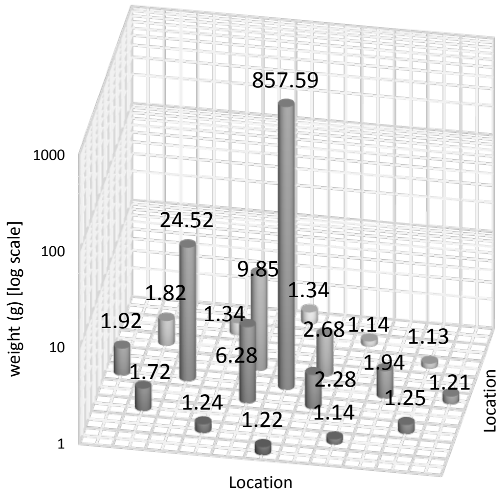
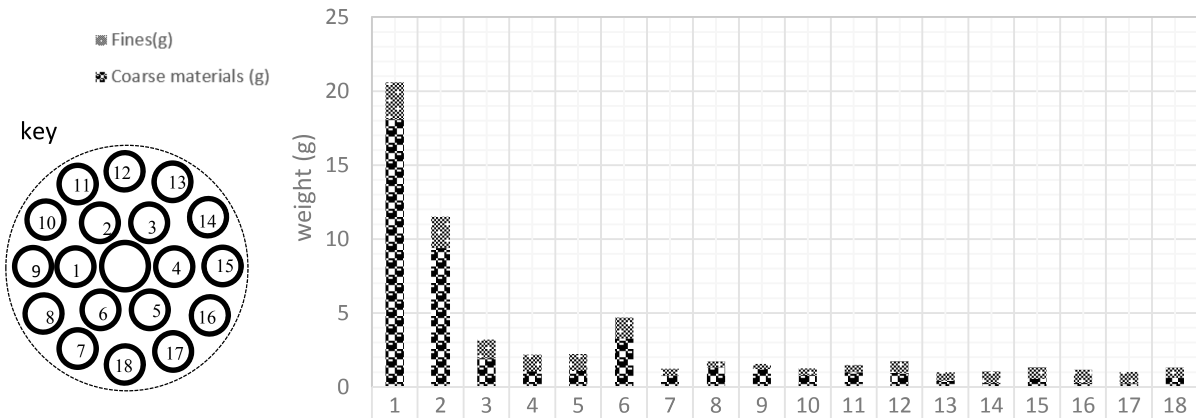


Figure 4 : mass distribution of Test 2

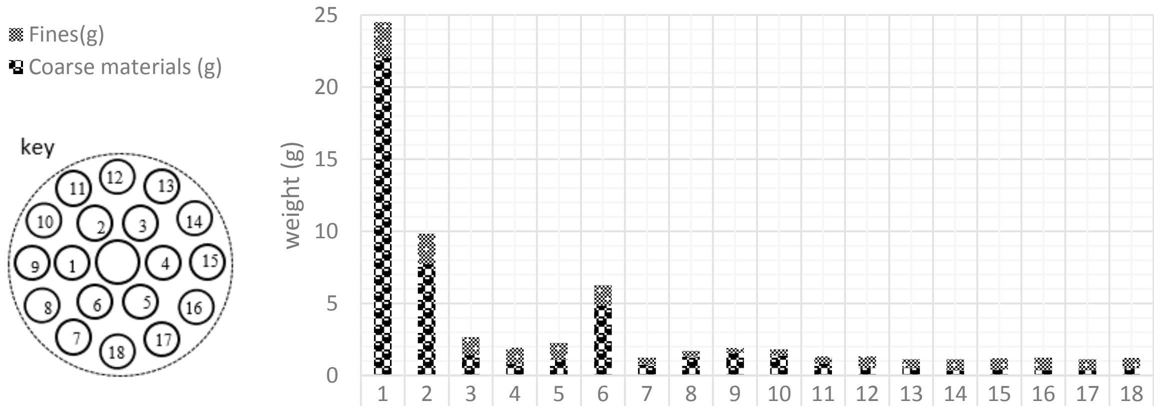
Figure 4 and 5 show the mass distribution is slightly off-centred and the distribution at the compartment 13 to 17 is very low. Furthermore it is clear that there are more materials dropped towards to the left side of the collectors. But still the results can be considered as an almost symmetrical distribution. It shows that the most of the coarse materials dropped straight on the bottom of silo.

3.2 Particle size distribution



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Fines(g)	2.5	2.1	1.3	1.1	1.2	1.4	0.5	0.4	0.3	0.4	0.5	0.8	0.6	0.8	0.8	0.9	0.8	0.7
Coares materials (g)	18	9.4	2	1.1	1.1	3.3	0.8	1.3	1.2	0.8	1	1	0.4	0.3	0.6	0.3	0.2	0.6

Figure 6 : Distribution of individual components for Test 1



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Fines(g)	2.5	2.1	1.3	1.1	1.2	1.4	0.5	0.4	0.3	0.4	0.5	0.8	0.6	0.8	0.8	0.9	0.8	0.7
Coarse materials (g)	22	7.7	1.4	0.8	1.1	4.9	0.8	1.3	1.6	1.4	0.8	0.5	0.6	0.3	0.4	0.4	0.4	0.5

Figure 7 : Distribution of fines for Test 2

The centre compartment contains 786.06 grams of the coarse materials and 49.76 grams of fines. As a percentage 5.74% of middle compartment contains fines. Which is a significantly lower than the initial 10% (something like this…).
Figure 8 shows a higher percentage of fines from collector number 12 to 18 and figure 9 shows similar results from test 2. From that it is clear that the air currents carried fines away from the main particle jet to the edge of the silo. Even though the particle jet is slightly off centred a considerable amount collected at the centre collector.

3.3 Dust concentrations

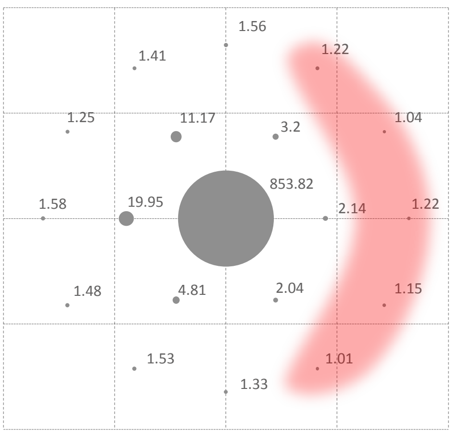


Figure 9 : Mass distribution and potentially explosive areas (red). (Test 1)

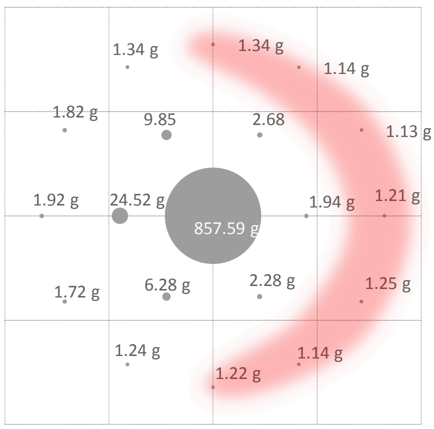


Figure 8 : Mass distribution and potentially explosive areas (red). (Test

Figures 8 and 9 show that there are areas with higher dust concentrations. According to Eckhoff et al. the range of explosive dust concentration is between 100 g/m^3 to few kg/ m^3 [5]. Figures 6 and 7 shows that collectors 14 to 17 have more than 50% dust from the total of both coarse and fines. Therefore there will be a risk of explosion when filling a large scaled silo.

3.4 Segregation index

The segregation index introduced by Zigan et al. [1] has been used to calculate as shown in the equation (1).

$$I_s = \sqrt{\sum_i \left(\frac{M_i}{M_L} \times \left[\frac{c_i - c_L}{c_L}\right]^2\right)} \tag{1}$$

c_i Mass fraction of fines in compartment i
M_i Mass of powder in compartment i
c_L Mass fraction of fines over all compartments.
M_L Total mass of all compartments.

The segregation index has been calculated for both test 1 and test 2 in order to have an idea about the segregation.

Segregation index of test 1 = 0.2795
Segregation index of test 2 = 0.3210

(The above results were taken at the discharge rate of 4.91 kg/min (10.57 Liter per minute). The air extraction rate was the same value as the filling rate.)

4 CONCLUSIONS

It was observed that the fine particles of the material comes to the terminal velocity quickly while the coarse particles remain under the gravitational acceleration for a longer time. The air-currents inside the silo take fine particles away from the main jet. This observation was very clear in the video footage as well as in the pictures, for example (refer to the figure 3).
Therefore it is necessary to do a simulation with two way coupling method. Which will show this phenomena and it will be useful in further understanding.
The experiment confirms the prediction mentioned in the beginning. Which is the concentration of fines in the outside compartment depends on the patterns of the air-currents created by the falling particle jet.
Particle stream is falling slightly off the centre. And the flow shows a spiral pattern consisting of coarse particles. This can only be examined through a simulation or high speed video footage. A simulation with two way coupling will help to better understand the physics behind these observations. Finally it is necessary to focus about shape of falling particle jet.

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